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MEASURING WATER

BY

CLEMENS HERSCHEL

Hydraulic Engineer

Member of the Boston Society of Civil Engineers. Member of the American Society of Civil Engineers. Member of the Institution of Civil Engineers of London.

AN ADDRESS TO THE STUDENTS

RENSSELAER POLYTECHNIC INSTITUTE

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FIGURE 1. TYPE "M" COMBINED INDICATOR AND CHART RECORDER FOR THE VENTURI WATER METER.

A new instrument made by Builders Iron Foundry. The lower dial indicates the rate of flow, and the upper dial makes a continuous autographic record of that rate on a circular chart.

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Measuring Water

By Clemens Herschel, Hydraulic Engineer.

THE subject which I have selected for this discourse may be called "Measuring Water," or to particularize, the measurement of a *stream* of water; being the determination of the cubic volume of water that thus passes a given point in the adopted unit of time. For most purposes the unit of volume, when using English measures, has been agreed upon in favor of the cubic foot, and the nations of the earth being fortunately agreed upon their measures of time, have settled upon one second of time as the unit to use in measuring water. Nevertheless, the million United States gallons in twenty-four hours has become a standard for city water supply practice in the United States, and an acre in area covered an inch, or a foot, deep in a month, or in a year, is used in irrigation practice. But I would warn all engineers to be very slow to add to the number of such standards of measure for flowing water, and to abstain from and frown down such absurd standards as cubic yards per day, or tons weight of water per day, or even cubic feet per minute (instead of second) and other incongruities found mainly in the writings of British engineers. As exercises in the art of arithmetic for children, such computations may have value, but in the work of civil engineers they become a

stumbling block to an advance of knowledge, and while unduly magnifying the unessentials, they indicate a deplorable lack of appreciation of the essentials of the art of the civil engineer.

Cubic measures do well enough for the contents of vessels, or as we may express it, for dealing with the science of hydrostatics. But so soon as the water to be measured is in motion, or so soon as the science of hydraulics has been entered upon, we must get clearly in our minds the idea of rates of flow, or of a procession of such cubic volumes passing a given point in a certain unit of time, as of a flow of so many cubic feet per second.

No such idea appears to have formed part of the stock in trade of the ablest engineers in ancient times, or at the beginning of the Christian era, nor probably for some 1,500 years later. Thus Frontinus, perhaps the earliest writer on practical hydraulics that we have, has barely a conception of the fact that some streams of water flow faster than others, but his measurement of any and of all streams is based solely upon the areas of their cross-sections. You can readily see how imperfect is such a conception of the volume of a flowing stream; though we must admit that to this day many a man yet struggles with the similar crudities of "the amount of water that will fill a 6-inch pipe," or of so many "square feet of water" let upon a water wheel and the like; when, as has been said, he might as well attempt to define the volume of a cylinder, or of a parallelopipedon by giving only the area of its base.

A stream of water, then, is defined by stating what it will produce in a unit of time; usually the cubic feet it will produce in one second of time. And this definition could not become current even among experts until con-

siderable attention had been paid to measuring the velocity of running water. These measurements, again, had their origin in the search for the numerical values of velocities of efflux through orifices and out of vessels of water; in the establishment of the equation, known to all of you, the fundamental equation of the whole modern science of hydraulics: $v = \sqrt{2gh}$

You may know that this equation was first published in 1732 by John Bernouilli of Basle, Switzerland, though his son Daniel Bernouilli was credited by his father with having furnished an independent proof of the same relation between head and velocity of efflux, at the time, and in 1738 the son published his own celebrated "Hydrodynamica." But these two founders of the modern science of hydraulics had been preceded by, and had had the benefit of the labors of many generations of earnest workers in the applied sciences. If I may be allowed to quote from myself, I give you on this point an extract from my lecture on "Frontinus and his II. Books on the Water Supply of the City of Rome, A. D. 97," published in the 1894 number of the Journal of the "Association of Civil Engineers of Cornell University:" "We who have been educated in English-speaking countries have been accustomed to consider Lord Francis Bacon (1561-1626), as the author and apostle of the experimental method of studying science. But modern research shows him to be entitled to the latter credit, only as he influenced his countrymen of Great Britain, and he himself made no experiments of any note. For a hundred years before his time lived that remarkable painter, sculptor, teacher and engineer, Leonardo da Vinci (1452-1519), the misfortune of whose fame it has been that his voluminous works, hidden away for centuries in private

keeping and exposed to manifold vicissitudes, found no publisher until the last few years; and have, even to-day, not been before the public long enough to be used by modern writers, as they undoubtedly will be. He not only preached the duty of study by means of experiment, but was himself a most prolific experimenter and a teacher. In the last named way he anticipates Lord Bacon; in the other he is the forerunner even of Galileo. His experiment of the law of falling bodies is most interesting in connection with the matter we are now considering. He used two long boards hinged together like the leaves of a book. On the inside, these boards were smeared with tar or wax. A string latch served to suddenly close them. He then takes a small tube, filled with shot, the tube having nearly the same diameter as the shot. This tube is held vertically in and over the angle of the wooden book, itself set up vertically. The shot are then allowed to drop out, and on pulling the latch, are caught as they fall, between the leaves of the wooden book, and their relative distances, as they are falling, are impressed on the tar or wax covering of the boards.

Until quite recently Galileo has been supposed to have been the first experimenter on the laws of falling bodies, but here was this great engineer and teacher busily at work at it, 100 years previously. However, with Galileo, (1564-1642), we first touch the modern science of 'dynamics,' or of bodies in motion. Says Rühlman: 'for the proper founding of the science of dynamics, or of the science which treats of the causes and the laws of motion, were requisite talents of a degree of eminence, such as the Lord Almighty called into being with Galileo in the year 1564.' But Galileo had no proper means for

measuring time, no clocks or watches. Both he and his son tried to make a clock, but did not succeed. Instead, he used a large bowl of water, having a small orifice at the bottom, and compared times by the weights of water discharged during these times, using his finger to start and stop the flow of water out of the bowl. As we shall see, it is a reasonable assumption that this makeshift of a clock became, in the hands of Galileo's pupils, and of those of his pupil's pupil, the suggestion for an experimental demonstration of the laws of efflux in general.

Castelli (1577-1644), the pupil of Galileo, was a Benedictine monk, from the same Monte Cassino which saved Frontinus' commentary to posterity, and he first showed that the quantity of efflux, in a given time, depended by law on, or was a function of, the depth of water in a bowl, such as the one just spoken of; that is, was a function of the head. But he wrongly stated this law, making the quantity vary directly as the head. It was his pupil, Toricelli (1608-1647), the inventor of the barometer, the grandson, in a professional sense, of Galileo, who first proved, in 1644, or only two years after Galileo's death, that the velocities of efflux are as the square roots of the head. But this still furnished no numerical value for the velocity of efflux. Still another, and still other great men, had to devote their lives to this cause. Thirty more years had to pass by, till Huygens (1629-1695), the inventor of pendulum clocks, first found the numerical value of the acceleration of gravity, commonly represented by the letter g in 1673, and sixty-five more years had to elapse, until the genius of the two Bernouillis, father and son, in 1738, or 250 years after Leonardo da Vinci, finally laid the foundation of modern terminate hydraulics by writing the equation of $v=\sqrt{2gh}$.

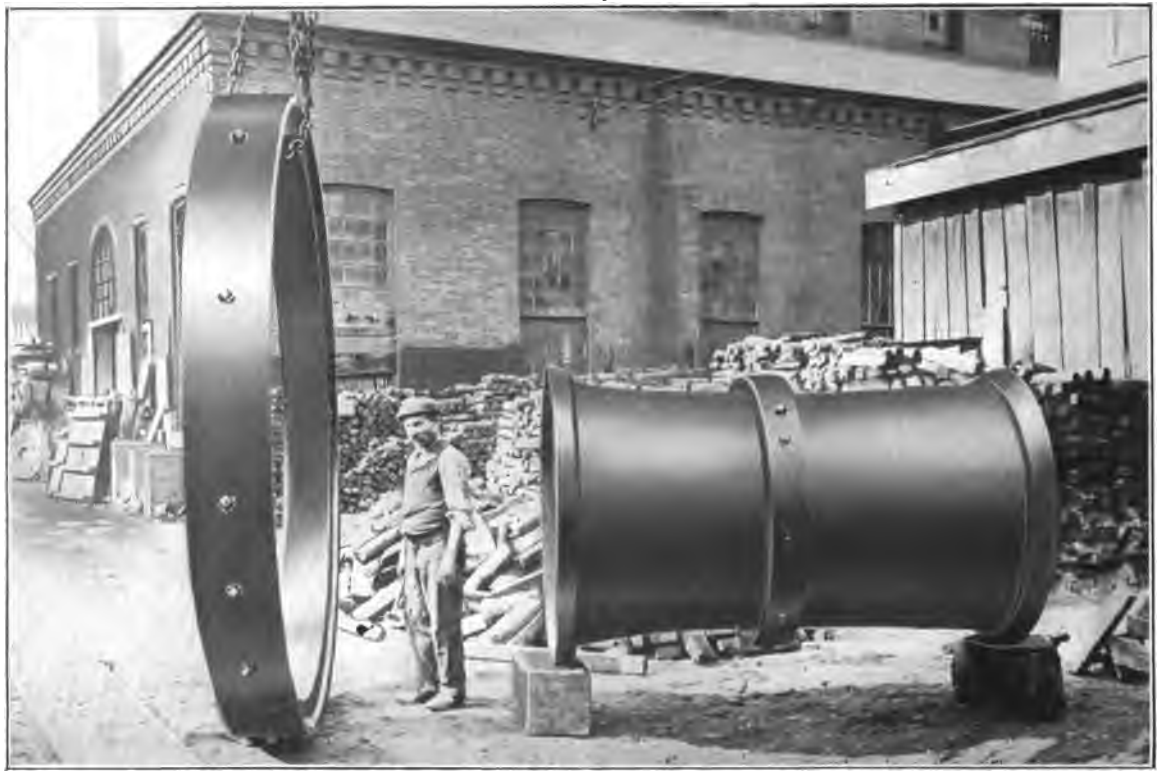

FIGURE 2. 102 INCH VENTURI METER TUBE, MADE BY THE BUILDERS IRON FOUNDRY IN 1908 FOR MONTREAL, CANADA. THE CONES ARE MADE OF RE-INFORCED CONCRETE.

every letter and character of which may be considered the contribution of and a tribute to the skill and perseverance of one or more of the many great men I have named. *v.* may stand to symbolize the experiments of da Vinci and Galileo, $2g$. alone would suffice to immortalize Huygens, were he not already permanently distinguished by his invention of pendulum clocks and other works; *h.* may serve to re-call Castelli, and the square root sign, his pupil, Toricelli, and when next we write the formula, let us remember that it took 250 years of work, not to speak of another and a preceding 250 years or more of speculation to put it upon the blackboard of the world. But no amount of speculation alone, or of peripatetic philosophy, would have produced it. To do that, the work of centuries of earnest men, not too proud to dip their hands into bowls of water, and to *experiment* in hydraulics, the while they were wearing mechanics' overalls, so to speak, was absolutely necessary."

Men of this stamp have followed, since 1738, in rapid succession, and were hydraulic observatories endowed with but a small portion of the wealth that has been devoted to furthering astronomical recreations, very much more such work would have been done up to the present time. Indeed it is sad to consider how much has been as yet withheld or lost to the world for the want of endowed hydraulic observatories. It was Galileo, who more than 200 years ago deplored this state of affairs, and declared that, strangely enough, he could learn more of the movements of Jupiter's satellites than he could of a stream of water on the earth which he inhabited.

But working in the best way they could, the practical part of the science of hydraulics and the art of measuring water has been developed since 1738 by many earnest

workers in this field, some of whom I will name in the order of their birth:

Michelotti, the elder,	1710 to 1777
Brindley,	1716 to 1772
Chézy,	1718 to 1789
Smeaton,	1724 to 1792
Bossut,	1730 to 1814
Du Buat,	1732 to 1787
Borda,	1733 to 1799
Venturi,	1746 to 1822
Prony,	1755 to 1839
Woltmann,	1757 to 1837
Michelotti the younger,	1764 to 1846
Eytelwein,	1764 to 1849
D'Aubuisson,	1769 to 1841
Thomas Young,	1773 to 1829
Bidone,	1781 to 1839
Poncelot,	1788 to 1868
Lesbros,	1788 to 1867
Darcy,	1803 to 1858
Weisbach,	1806 to 1871
Francis,	1815 to 1892

and by Boileau, Bazin, Borneman and a host of others still living, as well as many, such as Pitot, Cabe, and others of the years prior to 1738. These are the men to whom we owe the present state of the art. It is true that much that they have done, has become nigh useless in the practical pursuit of measuring water; but all science, all knowledge is thus developed with the accompaniment of a great waste of enegies, somewhat as the operations of nature include a waste of labor and of benign possibilities. Thus the multitude of experiments on efflux from vessels and through orifices can find but little use in practice. The intent seems to have been to so study efflux as to deduce its laws up to the point of being

able to meter water from a knowledge of the size and shape of the orifice and the head acting upon it. Speaking from the standpoint of the practician, this has not been accomplished, nor is there any present outlook that it ever will be accomplished. Each shape, each minute variation of shape, each accompanying circumstance of efflux, varies the co-efficient of discharge; so that the most that can ever be affirmed is that a precise reproduction of an orifice that has been experimented on and a reproduction of the attending conditions will reproduce the experimental discharges. This is the sum total of our knowledge even in a case apparently so simple as that of water wasting over a weir. I say apparently so simple, because as long known, the latest experiments of Bazin have clearly shown the multiplicity of forms according to which water may proceed to spill over a weir.

Returning to the case of discharge from an orifice, we have here probably the earliest method devised for measuring water. Frontinus, who wrote A. D. 97, described how water was metered to the Roman water-taker. It was led from the aqueducts to a group of cisterns set up near the places of final consumption of the water, and into the walls of these cisterns were inserted bronze, circular, ajutages, about nine inches long, of the desired diameter stamped with their size and the name of the water works superintendent who had set them. Two specimens of these ajutages have survived the wrack and ruin of the centuries and are preserved in two of the Roman museums. Frontinus knew that these ajutages must all be set on the same elevation, that is, as we would now say, under equal heads, to cause them to discharge equal volumes, but to show you how crude were his ideas, and those of the most learned of his contemporaries on

these subjects, I quote what he says about it: "In setting ajutages care must be taken to set them on a level and not place the one higher up and the other lower down. The lower one will swallow up more; the higher one will suck in less, because the current of water is drawn in by the lower one." Frontinus, 113.

Frontinus also knew that the ajutages must be set with their axes at right angles to the trend of the current, and that they would discharge more or less than the ajutage set at right angles, if set inclining with or against the current; finally, he knew that a large pipe attached to the down-stream end of the ajutage would carry more water than a pipe of the same diameter as the ajutage, attached in the same manner; and a law of ancient Rome prescribed that the diameter of the attached pipe must be the same as that of the ajutage, for a distance of 50 feet down stream from it. But with these precautions Frontinus apparently exhausted his means of measuring water, and the resources of his time, to the end that the measurements should be consistent among themselves. His unit was the discharge of such an ajutage 5-4 of a digit (about 0.907 inch English) in diameter; which he calls a quinarium, or as we would say, a "fiver." For an ajutage of double this area, the discharge becomes two quinaria, by reason of such double area; and so on, even up to the measurement, by a cross-sectional area of the stream flowing in an aqueduct, of the discharge of that aqueduct.

Of course, work like this can represent only an embryonic state of the art of measuring water. But it endured for yet 1,543 years, until Castelli, the pupil of Galileo, saw that more water was discharged out of a hole in the bottom of his water-clock bowl when the bowl had much water in it, than it did when the bowl was nigh empty, and published his ideas about it, as we have seen, in 1640.

From this time on, especially after the proof by Toricelli, only four years later, in 1644, that the discharge varied as the square roots of the head of water on the orifice, the importance of the head of water became firmly established. Frontinus had said that ajutages should all be on a level, but it is not known at what level he set them. Old orifices for regulating and limiting, not measuring water, used for irrigation purposes in the fourteenth and fifteenth centuries in Italy, had the ordinary water level even with the top of the rectangular orifice. In 1764 the legal *measure* of water used for irrigation was established in Modena, as the amount flowing out of a defined rectangular orifices under a defined head, and this is one of the earliest recorded uses of a fixed head on an orifice to define a measure of water in irrigation practice.

Long before this, however, it had become customary among the workmen that had charge of the public fountains of Rome and of Paris to measure volumes of water by the discharge through a circular orifice in a thin vertical plate; the unit in Paris, for example, being the discharge through an orifice one Paris inch in diameter. Belidor, who wrote in 1737 says (Archit. Hydr. 1-1, 366) that the "fountainers" were not particular what head was acting on the orifice so long as it was a moderate one. Their subdivisions of the water inch were also entirely irrational and erroneous. The first one who attempted to determine the meaning of a water-inch in fixed measures was Marriotte, who lived 1620-1684, and who found the discharge of a Paris water-inch, when the head on the upper edge of the orifice was 1 "ligne," about 1-12 of an inch, to be about 14 "pintes" per minute, = about .47 cub. ft. per minute. The Paris inch was about 6 per cent.

larger than the English inch; and with Gallic perversity the Paris "pinte" differed less than one per cent. from the U. S. quart.

Belidor notes somes of the many objections to this mode of expressing a definite measure of flowing water, and strove to improve upon it by substituting rectangular orifices of uniform height, set on a level, but having varying widths, for the circular orifices of varying diameter used in his time, whose centres or bottom edges were all on a level. The method is, however, necessarily beset with so many chances for error that it never can succeed for work that aims at the merest rudiments of exactitude. Again and again in the world's history has it been attempted to introduce it, in every case by uneducated men, or in crude forms of society, only to reveal its manifold imperfections and to vex and encumber the contracts and legislation of several succeeding generations before it could be got rid of. The miner's inch, gradually disappearing in our Pacific States in favor of the cubic foot per second, is one of the latest examples of the statement just made.*

The reason for this is readily seen when the multitude of dimensions and forms of the measuring apparatus, each one of which has an influence on the discharge produced, are taken into consideration. Whether the orifice be cut out of a plate 1-16 inch thick or 1-32 inch thick, or through an inch board or a half-inch board; whether the bottom of the vessel be 1″ or 3″ below the bottom of the orifice, whether the orifice be filed off smoothly or left as cut, whether the holes be punched 2″ apart or 3″ apart, and a multitude of other such circumstances, all

* See a report to the Montana Soc. of C. Engrs., by Prof. A. M. Ryon, 1894. Also Journal of the Association of Engineering Societies, January, 1895.

effect the resultant discharge. The one thing to do with such a crude unit of measure of flowing water is to get rid of it, and this is happily being accomplished in the course of time.*

Starting with the Roman attempt to measure flowing water merely by the cross-sectional area of the stream, thence passing to the mediæval way of measuring it by the number of streams one inch in diameter, under some small head, which it would produce, thence reaching the point where these small streams were defined to act under a given head, so as to regulate the affecting circumstance of discharge of greatest importance, we have at least arrived at the modern method of defining flowing water in cubic measure per unit of time, or at the definition of cubic feet per second.

I will ask you now to distinguish between mere computations that indicate the discharge from orifices, through

---

*So long ago as the middle of the fifteenth century there was at least one man who saw the defects of an orifice of discharge, as a unit of measure, very clearly.

In Leonardo da Vinci's Manuscript F, (Venturi, Essai sur les Ouvrages, &c., Leonardo da Vinci, 1797, p. 20), may be found the following:

CONCERNING THE WATER THAT MAY BE DRAWN FROM A CANAL.

The quantity of water that discharges from a canal through an orifice of a given size may vary on account of many reasons:

1. By reason of the height, more or less great, that the surface of the water of the canal is over the opening.
2. By reason of the more or less velocity with which the water of the canal passes along the bank in which is placed the opening.
3. By reason of the sides of the opening being more or less convergent.
4. By reason of the thickness of the frame of the orifice being greater or less.
5. By reason of the shape of the opening being circular, or square, or triangular, or lengthened out.
6. By reason of the axis of the opening being more or less inclined to the direction of the bank of the canal.
7. By reason of its being more or less inclined to the horizon.
8. By reason of the opening being placed on a convex bank or on a concave one.
9. By reason of protuberances, or depressions in the bed of the canal opposite to the opening.
10. By reason of the air intermingling, or not intermingling, with the current of water that discharges from the opening.
11. By reason of the water discharging from the opening freely into the air, or discharging through an open conduit, or through a closed pipe.
12. By reason of this conduit having a cross-section greater or less than the orifice of discharge.
13. According as this conduit is of greater or less length.
14. According as the interior of the conduit is smooth or rough, straight or curved.

When it is considered that this was written before the invention of printing, and before Columbus discovered America, it becomes a marvellous exhibit of a thorough and searching analysis made merely by force of genius, and without aid from the teachings of hydraulic science, then as yet unborn.

Register House at St. Johnsbury, Vt. 10-Inch Venturi Meter.
The temperature is frequently 30 degrees below zero.

pipes, or in channels, from instruments and methods by which such streams are directly examined and measured. The last process alone we will call measuring water. It may also not be superfluous to ask you to distinguish that forms of apparatus that may be set to discharge uniformly certain given quantities, so-called modules, are likewise not included in the instruments and methods to be used for effecting a measurement of a given stream; nor are ordinary water meters, which measure volumes, but do not measure rates of flow. But I shall include in such instruments the weir, which may be reproduced in the precise form used to establish a given weir formula, so readily, that it has won a place for itself among water-measuring instruments, something that the orifices or pipes that have been named are not likely ever to accomplish.

But a weir measurement is only reasoning by analogy from the recorded results of measurements made over a like weir into some measuring tank, so that at the foundation of weir measurements, and at the same time as the simplest of all methods of measuring water, we have the measuring tank, or, as we may call it, the grocer's pint or quart measure. But when conducted with accuracy, measuring water by means of a measuring-tank is an art, to be learnt like any other, some features of which may now be illustrated.

Tank volumes may be measured in two ways: either directly by cubic contents, or indirectly, by first weighing the quantity contained and then computing the cubic contents from the temperature of the contained water and from its weight per cubic foot.

If the first method be followed, the tank must be built on purpose for it, extraordinarily strong and staunch,

so as not to change in shape when filled with water, and by no means to leak. If of wood, the wood must be water-logged. Levels of water must be measured with a hook gauge to thousandths and to ten thousandths of a foot. The form of the measuring-tank must be a regular one, all the corners straight, sides without warp and all linear measurements must be determined with extreme accuracy. You can readily see that it is easier to use a tank or vessel of almost any make and form and to weigh the contained water.

To limit the lengths of time during which the stream, whose flow it is desired to measure, discharges into the tank, the best way is to use a movable spout between the stream of water and the tank. A carefully tested stop-watch and an assistant to cause the spout to discharge the water on a given signal into the tank and again to one side of it, will determine the length of time during which the tank received the discharge to be measured within the fraction of a second. Large movable spouts of this sort, to control discharges of considerable volume, may be found described in Francis' Lowell Hydraulic Experiments, and in the description of the experiments made with the Venturi Meter, in the 1888 Vol. of the Transactions of the American Society of Civil Engineers.

Such measuring-tanks are the very simplest forms of water-measuring apparatus, so simple that they are not thought of many a time by the hydraulic engineer, whose head may be filled with the pages upon pages treating of the cases and the coefficients of discharge given in the text books, but duplicates of any one of which cases are so seldom met with in practice. Whenever a small stream of water is to be measured, one's first thought should always be the tank, the pint measure. When that is not

applicable it will be time enough to turn to other methods.

One such other method, we have agreed, shall be the weir. Now a weir may be looked upon in two ways: as a hydraulic study of the discharge of water over it, and, again, strictly as a method for measuring water. If the first view be taken into consideration, the last word has by no means yet been said upon the subject, and the latest may always be the best. But if the second named object be kept in mind, we have in Francis' Lowell Hydraulic Experiments nearly all that will ever be needed upon that subject. For the weir experiments recorded in that classic of hydraulic literature embrace all the cases of weir measurement that are ordinarily met with in practice. We have but to reproduce the conditions of those experiments to have the results at once known with the same degree of accuracy that distinguished the tank measurements recorded in this book. As is well known, no expense was spared in the conduct of the Lowell experiments to ensure extreme accuracy, and as a consequence the boon of exact knowledge on the cases of weir discharge treated in the book named has been conferred, by these experiments on succeeding generations.

Another useful method of measuring water, applicable, however, when accuracy is desired, only in rectangular channels and for the cases of a uniform flow during the hour or more required for the measurement, is presented by the use of floating tubes. This method is a very old one, having been first used by Cabeo, an Italian professor in 1646, but the method was first accurately tested, and established as a trustworthy method of measuring water, by Mr. Francis, as related in the book that has been named, in Lowell Hydraulic Experiments.

This was done by measuring the same streams of water at one and the same time, both over a weir, and by means of floating tubes. It will not be in the power of man, presumably, for many years to add profitably to what is said on this method of measuring water in the book that has been referred to.

We now come to two instruments that enable us to determine the velocity at any *point* throughout the cross-section of a stream of water. I allude to the current-meter, or moulinet, or Woltmann wheel, and to Pitot's tube.

For small streams of water, for jets, or in the interior of pipes, the latter instrument alone is applicable for a close investigation of the distribution of the velocities of the water in the cross-section of the stream. In large canals and rivers the current-meter becomes not only the superior instrument, but almost the only practicable one. Many instruments have been invented for the same purpose, or were invented in the early days of hydraulic science, but are of no more practical interest now than would be an examination of the bones of extinct animals.

Woltmann, the inventor of Woltmann's wheel, was an hydraulic engineer employed by the City of Hamburgh, who lived from 1757 to 1837, and got his idea of the current-meter from an anemometer in use in his day. Since then the instrument has been constructed in a great number of ways. At first it had to be taken from the water after each time of running some definite period of observation to get the reading. Latterly, electrical or phonetic connection is made between the meter under water, and some form of counter above water, so that observations may be made continuously. The form of wheel, also, has changed many times. Care should be

taken that the wheel be as little liable to change of form as possible, and that all parts, such as bearings that produce frictional resistance, be as constant in condition as possible. All this is so that when once rated, the instrument may not be subject to a change of rate. It is not exactly correct to assume that the method of rating usually pursued, that of dragging the meter through still water at known velocities, is mathematically equivalent to letting the water, moving at an average velocity, equal to these same velocities, impinge upon the meter held still. Preliminary reasoning would so indicate, it is true, but a closer examination reveals differences, and in hydraulics reasoning alone will never indicate the weight to be given to objections or to analogies. To do this, resort must always be had to the results of careful experiments.

A valuable attribute of the current-meter is the fact that it can be used to measure the *average* velocity in a vertical, or in a horizontal, or in a whole cross-section, by slowly moving the meter over these lines or areas and exposing it to the current for equal lengths of time over equal spaces or areas. Some excellent work of thus integrating the velocity in the cross-section of a stream and other results of experiments with the current-meter may be found described in an article by F. P. Stearns, M. Am. Soc. C. E., in the Transactions of that Society for August, 1883; and the reports of the Corps of Engineers, U. S. A., contain many examples of the use of the current-meter on the rivers of the United States. See also *Engineering News* of January 10, 1895. In Europe, also, in Germany and France, much work has been done with it.

The modern use of the Pitot tube may be likened to

FIGURE 4. ONE OF THE VENTURI METER TUBES MADE BY BUILDERS IRON FOUNDRY FOR THE EAST JERSEY WATER COMPANY.

that of a microscope in hydraulic investigations when compared with that of the current-meter. It is a very old form of current measuring apparatus, Pitot having lived from 1695 to 1771, but the instrument has received many improvements at the hands of Darcy and Bazin, and of many others. The point of a Cross Stylographic Pen, with the central wire removed, has been a favorite form of the tube which is directed against the current to be measured, and this characteristic feature will give an idea of the delicate work this instrument is capable of. Some excellent investigations of this sort are described in the Transactions of the American Society of Civil Engineers for November, 1889, page 411, in a paper on Fire Streams by John R. Freeman, M. Am. Soc. C. E.

Another method of measuring water is by means of the Venturi Meter, which has further been converted by the attachment of a suitable register into an ordinary dial meter, like the house meters commonly met with. There being hardly a limit at which the size of the stream to be metered by this means becomes too large for it, and as the register is essentially the same for small meters and for the largest sizes, we could with the Venturi Meter register on a train of dials the daily consumption of the present or of the Greater New York, or of London, or of the two combined, as easily as that of a $\frac{1}{2}''$ stream. As a matter of fact, this meter has already measured the flow of water through a 9-foot tube up to over 245 cub. ft. per second, about 160,000,000 gallons per 24 hours. It has also been tested on a $\frac{1}{4}''$ stream, and meters the one as readily as it does the other. Nor is it affected by nor does it materially affect the pressure of water either at the intake or the delivery end; that is to say, it can be used on pipes under any pressure and destroys very little of the

head or pressure for purposes of passing the water through the meter. For instance, it need never thus destroy more than a foot of head when passing maximum quantities. A 48″ meter in use on the works of the East Jersey Water Company, for example, loses 4 inches of head to meter 25,000,000 gallons per day. And by the use of by-passes, any loss of head need obtain only during the period of measuring water.

These are some of the general characteristics of the instrument, which may now be described more in detail, the more so because its description has not yet been placed in text books generally, although Merriman's Hydraulics contains a good discussion of it.

HIGH PRESSURE FIRE SERVICE TEST ON WEST ST., NEW YORK CITY, JUNE 28, 1908. FOUR 24 INCH VENTURI METERS ARE USED TO SHOW HOW MUCH WATER IS PUMPED TO PUT OUT ANY PARTICULAR FIRE.

THE
VENTURI WATER METER

AND THE FIRST TWENTY YEARS
OF ITS EXISTENCE

BY

CLEMENS HERSCHEL

Hydraulic Engineer

Member of the Boston Society of Civil Engineers. Member of the American Society of Civil Engineers. Member of the Institution of Civil Engineers of London.

Reprinted by

BUILDERS IRON FOUNDRY

PROVIDENCE, R. I.

1909

Figure 7.

East London Water Works weir, and meter house; showing the discharge of a 48 inch Venturi Meter. The figures in the fore ground are the Directors and the Engineer of the Company.

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HISTORY OF THE INVENTION

"The labor of my discovery is done; there only remains now to find out how I came to do it."—KARL FRIEDRICH GAUSS, 1777-1855.

IN 1886 the inventor of the Venturi Meter was the Hydraulic Engineer of the Holyoke Water Power Company, of Holyoke, Massachusetts. This Company is one of those water power companies, found principally or perhaps wholly in the United States, whose business it is to grant or let "mill-sites," being the land needed for manufacturing buildings, and, generally, for tenements for the operatives as well; and appurtenant to the mill-sites, certain water-rights, designed to be sufficient in scope and efficacy to generate the power needed by the mill or factory. Such companies usually own the dam, or weir, and the canals that conduct the water to, and again away, from the several factories, and in order that they may have a perpetual pecuniary interest in maintaining the dam and canals even after all the mill-sites and the power have been sold or alienated, it is usually in some way provided that the company must reserve a portion of the purchase price of each mill-site in the form of a perpetual annual rental. This form of water power company was designed or invented by a no less great man and financier than Alexander Hamilton, Washington's choice for

Secretary of the Treasury in his first Cabinet; he of whom Daniel Webster said: "He smote the rock of the national resources, and abundant streams of revenue gushed forth. He touched the dead corpse of Public Credit, and it sprung upon its feet"; and the Society for Promoting Useful Manufactures, of Paterson, New Jersey, has the honor of having been the first (1791) of such companies; with Alexander Hamilton for its first legal adviser.

The influence of such water power companies in fostering manufactures in the young United States, and incidentally in giving opportunity for the training and practice of hydraulic engineers in the United States, has been very great, and will never be forgotten. Let us mention only the name of James Bicheno Francis, 1815-1892, whose Lowell Hydraulic Experiments will ever remain a classic of engineering literature; and whose pupils and pupils' pupils, are passing on as well as they may, the torch of enlightenment, of a homespun skill in their profession, and of a trained, well-balanced judgment, which he loved to illustrate to them.

At the present day, companies of precisely the nature described, are no longer being organized. Indeed the time has come when in certain cases it would be materially profitable to convert such companies, and they should be converted, into the modern form of power company; which distributes power on wires, instead of distributing water through canals, as was the old-time method. The large areas of land hitherto occupied by the canals, could then be sold or used for other purposes; the proceeds of such sales possibly paying for the whole improvement; while much power now wasted by hydraulic losses in long canals and at many power plants

would be recovered and all the power to be distributed and used, would be generated at and distributed from one Central Power Station.

But in 1886 the Holyoke Water Power Company was yet a model water power plant, and the measurement of the water consumed by each of the 90 odd turbines of its tenants, many of them running continuously from Sunday midnight to Saturday midnight; and the making out of quarterly bills for the excess of water, over and above their granted or lawful quantities, used by each tenant, called "surplus power," was an important, and, to the Company, an extremely profitable, part of the duties of the Hydraulic Engineer. This much of administration had been inaugurated and set in successful motion between 1880 and 1886.

But there was another draft of water out of the canals, unseen of human eyes, which sorely troubled the mind of the Hydraulic Engineer. This was the large quantity used by the manufacturing corporations, including some 25 large paper mills, as wash-water; roughly estimated at 10 per cent. of the quantity used for power. This water was drawn through cast-iron pipes, most of them 20 to 24 inches in diameter, painted black on the outside, and, there they lay, usually in the basement of the mill, silent as the grave, and most provokingly secretive of what was passing within their interior. Many a time did the Hydraulic Engineer stand beside such a pipe and exert himself to invent, *s' ingénier,* (whence our word: engineer), how to force these pipes to reveal the secret of their hidden action.

In course of time, between 1882 and 1886, these endeavors resulted in a determination at the first opportunity to try how an apparatus like this would work;

place an orifice at some point in the pipe, circular and in the form of an ajutage, from choice, and then place an expanding cone or ajutage, downstream from the orifice, in order that the loss of head occasioned by the first orifice may be regained, and no material loss of head be occasioned by the whole apparatus; all of this superimposed on the existing hydraulic gradient.

As will presently appear, the theory of the finished invention had little or nothing in common with that of the same invention in embryo; nor has its true formula—first set up many months after the invention had been experimented with—and according to which the finished invention acts, much, if anything, in common with the invention as it was pictured in the mind of the inventor, at any stage of its development. But it has always seemed of interest to the author, and a curious record of the manner of working of the human brain, to follow out in detail the birth and growth of this one invention; and as such curious example it is here presented.

In 1886, the Hydraulic Engineer received confirmation of his ideas and notions from an account of Bourdon's Anemometer* used in France to measure the velocity of currents of air in mines; and proceeded to design his water meter, then named the Venturi Meter, out of respect for the "Citizen J. B. Venturi," who, "An VI. (1797)" published his "Recherches Expérimentales sur le Principe de la Communication Latérale du Mouvement dans les Fluides." †

* Bourdon's Anemometer is described in *Annales des Mines*, 1891; also in *Comptes Rendus*, January 30th, 1882, P. 229. The Bourdon named, is the inventor and original manufacturer of the well-known Bourdon pressure gauges.

† See Tracts on Hydraulics, by Thomas Tredgold, second edition, London, 1836; or Nicholson's "Journal of Natural Philosophy," Vol. III., London, 1802, for English translations; Gilbert's Annalen, Vols. II and III contain a German translation.

Venturi's experiments were made in Modena, about 1791, and he had observed that when fluids or gases discharge through an expanding nozzle or ajutage, that a sucking action is exercised at the small diameter, diminishing as the diameter increases. But Venturi made or suggested no use to be made of this property, and with him it was merely a curious feature in the working of his apparatus. Nor did he correctly explain any of the properties observed.

Other engineers and investigators noticed the peculiar action of expanding nozzles, or of Venturi ajutages, as they came to be called, and made certain uses of it. Thus, Uriah A. Boyden, in his invention of the "diffuser," as applied to Fourneyron turbines; for which see Francis' "Lowell Hydraulic Experiments," Trübner & Co., London, 1868; or later editions of Weisbach's Mechanics.

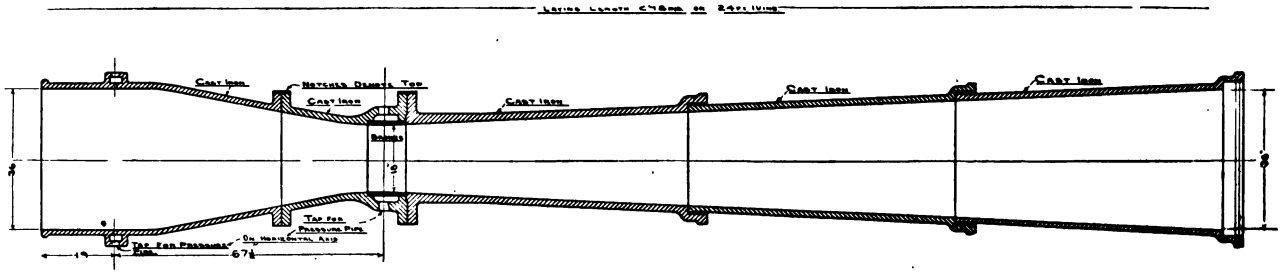
Nagel & Kaemp of Hamburg, used such a tube, as a pump, to suck water out of a foundation pit, while building a dam across a river. See "Zeitschrift des Ingenieur und Arch. Verein in Hanover," 1873.

Then came the Bourdon Anemometer, and next the Venturi Water Meter.*

The experiments detailed in Francis' "Lowell Hydraulic Experiments" had determined the shape of expanding ajutage, which would give the maximum discharge under a given head; and that is the same thing as a form that will cause the least loss of head with a given discharge, which was what the Hydraulic Engineer then wanted. And the rest was easily supplied.

This adopted form and construction of the Venturi water meter tube is shown in Figs. 1 and 2.

*See note A.



Scale $\frac{3}{4}$" = 1ft.

Order	36" Venturi Meter Tube Section for City of Chicago, Ill.	Builders Iron Foundry Providence, R I	Aug 23, 1906	Blue			15595

Figure 1.

Form and make of a Venturi Meter Tube.

It may be remarked at this point that from that day to this, the form, proportions and details of the Venturi water meter tubes have never been changed, although several skillful engineers have attempted to improve on the original form; by changing the summit angles of the cones; by making the cones trumpet shaped; and in other such ways.

But would it work at all? Were there unexpected difficulties in the way? How would the "coefficients" turn out to be?

Fortunately the Hydraulic Engineer had at his command, the Holyoke Testing Flume, which he had built in 1881 for measuring the mechanical efficiency, and incidentally the discharge, of turbine water wheels, for his company and for the public; and for thus converting each turbine to be set at Holyoke, into a water meter, before it was set; for purposes of the daily measurements made for the Water Power Company, above spoken of.

A one-foot, and a nine-foot Venturi Water Meter were accordingly built, and carefully experimented on, in June and October, 1887, as fully detailed in Transactions of the American Society of Civil Engineers, 1887. Another such meter, 4 feet in diameter, was tested in place, set in the line of the first 48-inch riveted steel pipe-line of the East Jersey Water Co., built in 1890, of which Water Company the Hydraulic Engineer had become Chief Engineer and Superintendent. The 1890 experiments are described in the Journal of the New England Water Works Association, for September, 1893; and these tests of a 1-foot, 4-foot and 9-foot Venturi Water Meter, constituted the only complete tests of such meters of large size made to date,

although many tests of the accuracy of single gaugings registered by the meter, have been made by many of the purchasers of the numerous meters now in use, literally the world over. Besides this, many 3 or 4-inch laboratory meters, set up in technological schools, have been annually tested by their consecutive classes of bright young men, studying practical hydraulics.

The results of all of these tests have uniformly shown a most remarkably small range of coefficient to be applied, for converting the theoretical discharge, into the true discharge. This will appear from the diagram on pp. 24 and 25, Fig. 3, giving the results of the experiments conducted by the writer in 1887 and 1891; which show that within the limits of ordinary use, the range of coefficient *of the three* meters, throughout the range of velocities tested, two of the meters [the 1-foot and the 9-foot meters] having a ratio of throat area to area at the inlet of 1 to 9, and the 4-foot meter having this throat ratio 2 to 9, is only between 1.00 and 0.94. These figures show what may be expected from *any* such meter put into use, without first rating it; but if first rated by tank measurement, such a well built meter would indefinitely continue to indicate quantities passing, within a small fraction of one per cent. of the exact quantity.

Let it be said at once, that only the most accurate of gaugings are competent to check, test, or control a Venturi Meter record, as now established. As such tests have been at times conducted, they have resolved themselves into the Venturi Meter testing the skill of the engineer who constructed the weir apparatus, or who is making the weir gauging. The two methods of gauging are somewhat in the relation of a piano, and of a violin, in striking a true note. The one requires for that

purpose only inexpert action; while the other requires both knowledge and skill to accomplish the same end; and is not likely to accomplish it, unless thus safeguarded.

The experiments of June and October, 1887, had been made and their results computed, on the supposition, merely, that, as Venturi had found, there was a sucking action at the throat of a Venturi Water Meter, and that the intensity of this suction would be found to have a valuable relation to the velocity of the water through the throat of the meter.

But as soon as the computations were finished, it became evident that a more rational view and a concise formula for representing the action of such meters was needed, and the author's paper in the 1887 Transactions of the American Society of Civil Engineers contains the true formula for such action.

According to modern methods of representing the forces at work, it will only be necessary to consider that at any section of a pipe-line, containing water in motion, the pressure against the walls of the pipe is equal to the pressure as it would be were the water still (the static head, or pressure head), less the head needed to produce the velocity existing along the walls at the pipe at that point (the velocity head). See Merriman's Treatise on Hydraulics, Art. 32, and many other text books; the original statement of this fruitful hydraulic theorem having been given by Daniel Bernouilli, 1738, Hydrodynamica, pp. 35, 144.

We have then:—

if v_1 is the velocity at the upstream end; and

v_2 is the velocity at the throat; also

h_1 and h_2 the corresponding pressures at those

Figure 4.

Three Venturi Water Meter Registers, with Chart Recorder; as made by Builders Iron Foundry, Providence, R. I. These three registers are set up at the Washington Filter Plant, North Capitol Street, Washington, D. C.

points when the water is in motion, expressed in heads of water; that

$h_1 + \frac{v_1^2}{2g}$ = hydrostatic head at upstream end, and

$h_2 + \frac{v_2^2}{2g}$ = hydrostatic head at the throat.

We thus have: $v_2^2 - v_1^2 = 2g(h_1 - h_2)$; and if Q is the discharge, and a_1 and a_2 are the areas in consideration, or $Q = a_1 v_1 = a_2 v_2$, we get:—

$$Q = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2 g (h_1 - h_2)}$$

When the throat diameter is ⅓ of the diameter of the main pipe, i. e. : — when $a_1 = 9\ a_2$; and H is the difference between the observed pressure at the upstream end and at the throat; then theoretically,

$$Q = 1.0062\ a_2 \sqrt{2\ gH}$$

Experiments have shown, as stated, that in effect, and ordinarily, for all sizes of such meters and of velocities through them,

$$Q = (0.97 \pm 0.03)\ a_2 \sqrt{2\ gH}$$

These two quantities must be equal; ignoring for the moment the matter of the slight loss of head between the upstream end of the meter and the throat.

This simple formula represents the action of the Venturi Water Meter as it has been established to date; and we have thus seen that an understanding of the correct principle according to which an invention operates may follow, and not precede, the making of the invention; indeed such understanding may come to the inventor, last of all; provided he do but sufficiently cogitate and experiment.

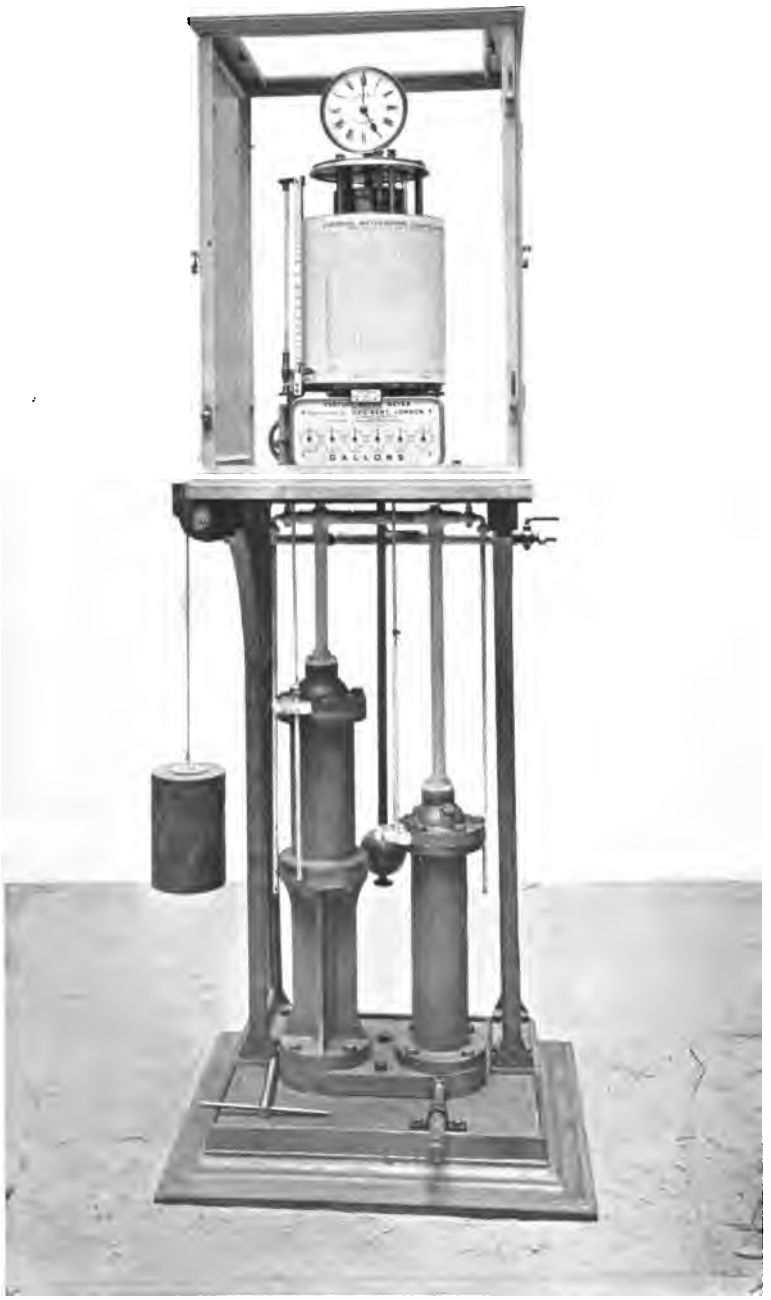


Figure 5
Venturi Water Meter Register with Chart Recorder; as made by Geo. Kent, 300 High Holborn, London, England.

Strictly speaking, the instrument described in this paper up to the present point, is not a water meter at all; only the beginnings of a water meter. It is an engineer's instrument, by means of which, and by observation and computation, he may laboriously arrive at the results of single gaugings. To complete the intended water meter, there is necessary the addition of a register, which is to be operated by the *difference* of pressure in the two pressure tubes; the one indicating the pressure at the upstream end of the Venturi Meter tube; and the other indicating the pressure at the throat. Such a register has been made in various forms, and Figs. 4, 5, and 6 show the two forms longest in use; and as made respectively by Builders Iron Foundry, of Providence, R. I., Fig. 4, and by George Kent, 200 High Holborn, London, Figs. 5 and 6. The dials, or counters, of these registers record the cubic feet or gallons or other cubic measure desired, that are passing through the meter tube; and this combination of tube and register at last constitutes the meter which it has been desired to produce.

There is a tendency in American engineering literature at the present day, to misuse the word meter. A weir, for instance, cannot properly be called a water meter; nor a Pitot tube in any of its forms; nor a rating flume, current meter, submerged orifice or miner's inch box. A nozzle, on the end of a hose, with a pressure gauge attached, has been called a meter, merely because it furnished indications of the quantity of water allowed to waste through it upon the ground.

But even in their most highly developed forms, all the instruments above named are only tools of the engineer, which necessitate, in addition, the high-priced

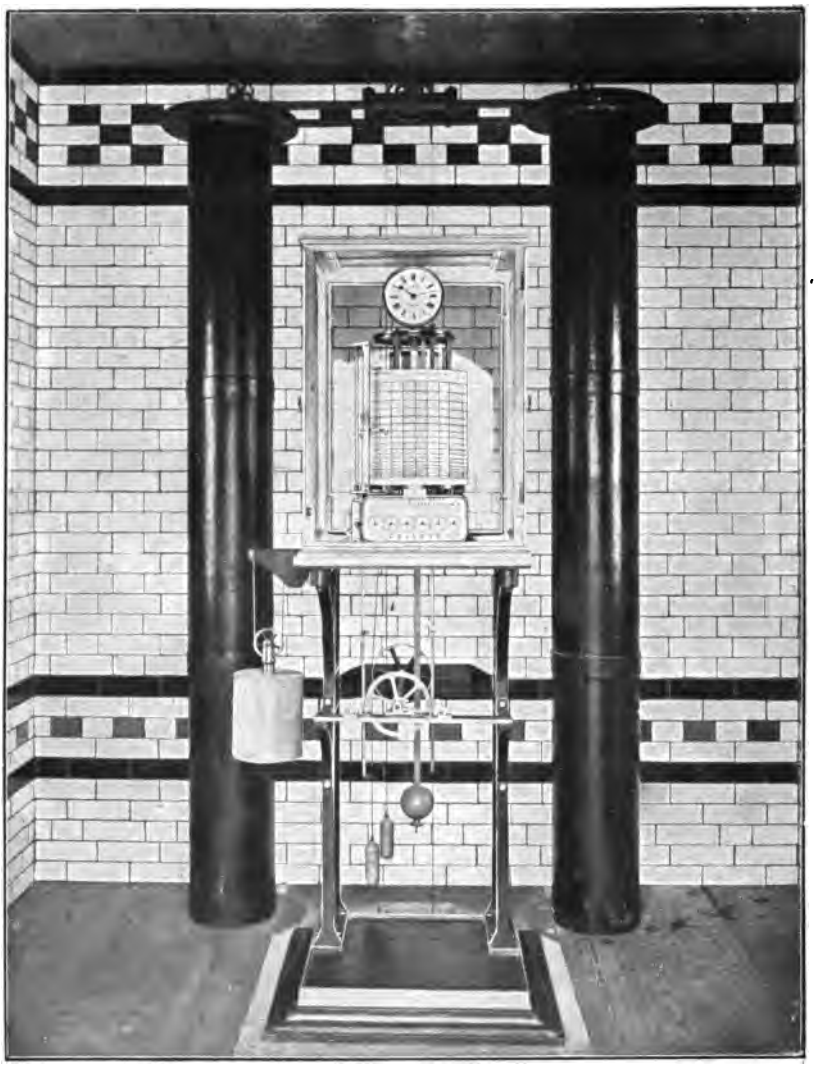


Figure 6.

Venturi Water Meter Register, for low pressures, as made by Geo. Kent, 200 High Holborn, London, England.

work of such an engineer, before even the results of the solitary gaugings he may be expected to make with them are recorded in his computation or note-book. It may be treason to the interests of the profession to point out this difference between the man under an engineer's salary using as skillfully as he may, certain tools and appliances, to get a few disjointed gaugings; as compared with a machine furnishing an accurate continuous night and day record of the flow through the main pipe under consideration; but this is the difference between the work of the man and his instrument, and that of the machine properly called a water meter.

Even a dial or a counter register, does not wholly satisfy in certain cases. A chart or graphical continuous record, is often wanted, and forms part of both of the registers above referred to. Such graphical records have further the great practical value of constituting night and day watchmen upon the water distribution, indicating accidents, neglect or theft, so that these may become instantly known, and their origin sought, cured and a recurrence prevented; as will presently appear.

Inasmuch as the two little pressure tubes that operate the register, contain water under pressure only (not in motion), they may be made to control the action of one or several mechanisms operated by their *difference* of pressure, without interference; and may also operate such registers, or chart recorders, or both, when placed several hundred feet distant from the meter tube; which is ordinarily buried in the ground, while the register is placed in some office, cellar, or other frost-proof, yet conveniently accessible location.

The accuracy of the whole meter naturally depends on the accuracy of the register, no less than on that of

the hydraulic principle embodied in the action of the meter-tube. The registers shown leave nothing to be desired on that score, though on well conducted works they are tested from time to time, to make sure; which can readily be done without stopping the flow of water through the meter. It is only necessary to compare the indications of the register with those of a bent glass tube manometer operated by the same two pressure pipes.

If a pipe or bye-pass were run from the upstream end, into the throat, water would flow through it, and a house-meter placed in line of this pipe would afford an approximate indication of the quantity passing the main pipe. In other words, instead of being a *direct* meter, the Venturi Water Meter would thus be made a *proportional* meter; but subject to the well known *defects and inaccuracies* of all proportional meters; one of the greatest of which would be their instability of rating, even though rated when first put into service. For these reasons the author has always opposed the manufacture of, and has studiously refrained from ever allowing his name to be used in connection with, such proportional meters, though the idea of thus making them is a very old one.

Before passing now from the history of the invention of the Venturi Water Meter to the teachings of the first twenty years of its use, it may be proper to add, that it and its registers were patented in the United States, Great Britain, France, and Germany. In 1898, the author received from the Franklin Institute of Pennsylvania, its Elliott Cresson Gold Medal for his invention of the meter tube;* and Messrs. Connet and Jack-

* See *Journal of the Franklin Institute*, 1898, Part 2, p. 80.

son, of the Builders Iron Foundry, received at the same time the John Scott Legacy Medal for their invention of the register. At the Louisiana Purchase Exposition. St. Louis, 1904, the Venturi Water Meter received the Exposition Gold Medal; and it has been otherwise commended and distinguished.

TEACHINGS OF TWENTY-YEARS' USE OF THE VENTURI WATER METER.

"Time trieth troth in every doubt."—JOHN HEYWOOD, 1565.

One of the first things that impresses the student of the experiments made with the Venturi Meter, is the small range of coefficients found; only about 6 per cent. For weirs this range is 12 per cent.; see Plate VII, Hamilton Smith's Hydraulics. For orifices, it ranges from 0.60 to at least 0.90; or 50 per cent. In fact, so great is this range, and so numerous are the coefficients to be found in the text-books, that this cloud of witnesses grossly obscures the view, when it is desired to apply a certain one of them to an orifice as it may occur in practice. It then becomes impossible to match the orifice at hand, with the orifice for which was found any one of the multitude of recorded coefficients, notwithstanding or perhaps on account of their very great number; and accuracy cannot be obtained.

That great master of experimental hydraulics, l'Inspecteur Général des Ponts et Chaussées Bazin, seems to have come to a similar conclusion with respect to the discharge over weirs. After attaining the multitude of coefficients called for by the numerous forms of weir with which he experimented and which are recorded in

his articles in Annales des Ponts et Chaussées, 1898 and previous thereto, he says that the most promising line of experiments for future development and for the perfection of the art, are those in which—ignoring water levels upstream from the weir, indicated and observed in any mode whatever—he measured the hydraulic pressures to be used in his formula of discharge, at the weir itself, by means of a pressure tube let into the body of the weir; in a manner similar to that in which the pressures at the upstream end and at the throat of the Venturi Meter were measured; and that in this way he attained coefficients having a much smaller range of value.

These considerations, which sharply refrain from commingling the hydrostatic with the hydrodynamic data of the case in hand, and confine themselves to a use of the hydrodynamic data alone, the present writer has treated more at length in an article entitled: "The New Hydraulics," in *Engineering News* of November 10, 1898. It is his belief that in the direction indicated lies the hope of rescuing the practical gauging of water from the fog of coefficients which now assails it, and of making of it a more practical, as well as more exact, art and science.

Twenty years' use of the Venturi Meter has wrought marked changes in the practical administration of hydraulic properties. The power that came with a knowledge on the part of the superintending engineers of the quantities that were passing within the conduits they had in charge, was a new and awakening revelation to them, and one that none of them have been slow to utilize. This same knowledge communicated to the water takers has been, if anything, of still greater value

to them. Elements of human nature, until then dormant, or impossible of being set to work for the attainment of useful ends, have been enlisted in the cause of thrift and of a much-needed economy, by means of the continuous record of large quantities flowing in conduits, such as the Venturi Meter for the first time furnished; as will presently appear; and plenty of other such work awaits the introduction and use of the meter.

Illustrations may be given from nearly all the classes of hydraulic works ordinarily met with:—such as a domestic supply to towns and cities, including waste prevention; water power plants; manufacturing plants; irrigation; and metering compressed air, steam or other gases.

DOMESTIC SUPPLY TO CITIES AND TOWNS.

It will have been observed that the Venturi Meter was invented to measure the wash-water used in paper mills. Shortly after, in 1889, the Hydraulic Engineer of the Holyoke Water Power Company was called to New York to construct the contemplated works of the East Jersey Water Company, a company which it was intended should supply in bulk quantities the water needed by a group of municipalities; and which did at one time thus distribute some eighty million gallons daily, to about a dozen cities and towns; the towns, or else the private corporations which supplied those towns, distributing the water received from the East Jersey Water Company, and collecting the water-rates from the inhabitants.

As it has happened, no wash-water has been metered at Holyoke from that day to this, but the invention of the Venturi Water Meter was exactly what was needed

in the drawing up of a rational form of contract for the supply of the municipalities and private water companies constituting the customers of the East Jersey Water Company; and for a rational construction of the works to carry out those contracts. Allusion is here made to the principle then first established and for the first time possible of being established; in both contracts and construction; of selling these large quantities of water *by measure;* simply—by the million gallons delivered at a designated point.

The success attending this innovation was immediate, and a marked one. Notwithstanding this, the greatest praise to be said of it is, that it was unremarked by the general public, and that it has never given rise to objection or dispute; though it has been imitated and adopted in scores of like instances.

More than that: a perfectly parallel case can be cited, of the Metropolitan Water Board of Massachusetts; chartered in 1894 and charged with the duty of building works and supplying water in bulk to some twenty municipalities; which was directed by the act creating it, to charge for the water delivered, by a scheme of taxation based on the population and valuation of the territory supplied; but has since been obliged to change to the system of selling by measure instead. The naturally to be expected consequences of the original plan of payment for water delivered were not lacking. There being no incentive in this scheme not to waste water, the waste of water in the towns and cities supplied, always large, increased from the day of the inauguration of the new works, and became extremely burdensome, causing additional supply works, costing many million of dollars and the destruction of a large

amount of water power, to become necessary a long time before it had been estimated that they would be requisite; with a prospect of this programme having to be repeated at unduly short intervals; and of bringing in its train a crushing taxation, and other inconveniences. So marked was this tendency that the Governor of the Commonwealth, by message, interfered in 1902, and since then the whole scheme of taxation described has been changed, so as to cause quantity delivered to be a chief factor in the computation of amounts to be paid; with a prospect of eventually having these water rates based wholly on quantity delivered. These works could not practically have been placed under the form of administration for water delivered which now controls them, except for the timely invention and application of the some sixty Venturi Meters now used in their operation. And the Venturi Water Meter is today, as it has been, the only water meter, so far as the author knows, by means of which work like this may be effectively and safely done.

Another instructive case is the City of Bayonne, New Jersey. This is a city that formerly allowed another city to supply it, under a contract based on a sharing of house to house water receipts; these, again, based on a graded tax on described water fixtures, instead of on quantity. Under this regime, 100 gallons per inhabitant was considered a moderate draft for domestic consumption (excluding manufacturing). But when the city began to buy water by the million gallons, it soon saw the wisdom of selling to its own citizens by the 1,000 gallons, and of properly caring for its distribution system besides. It adopted the system of selling by meter; proceeded to meter every tap; and some years

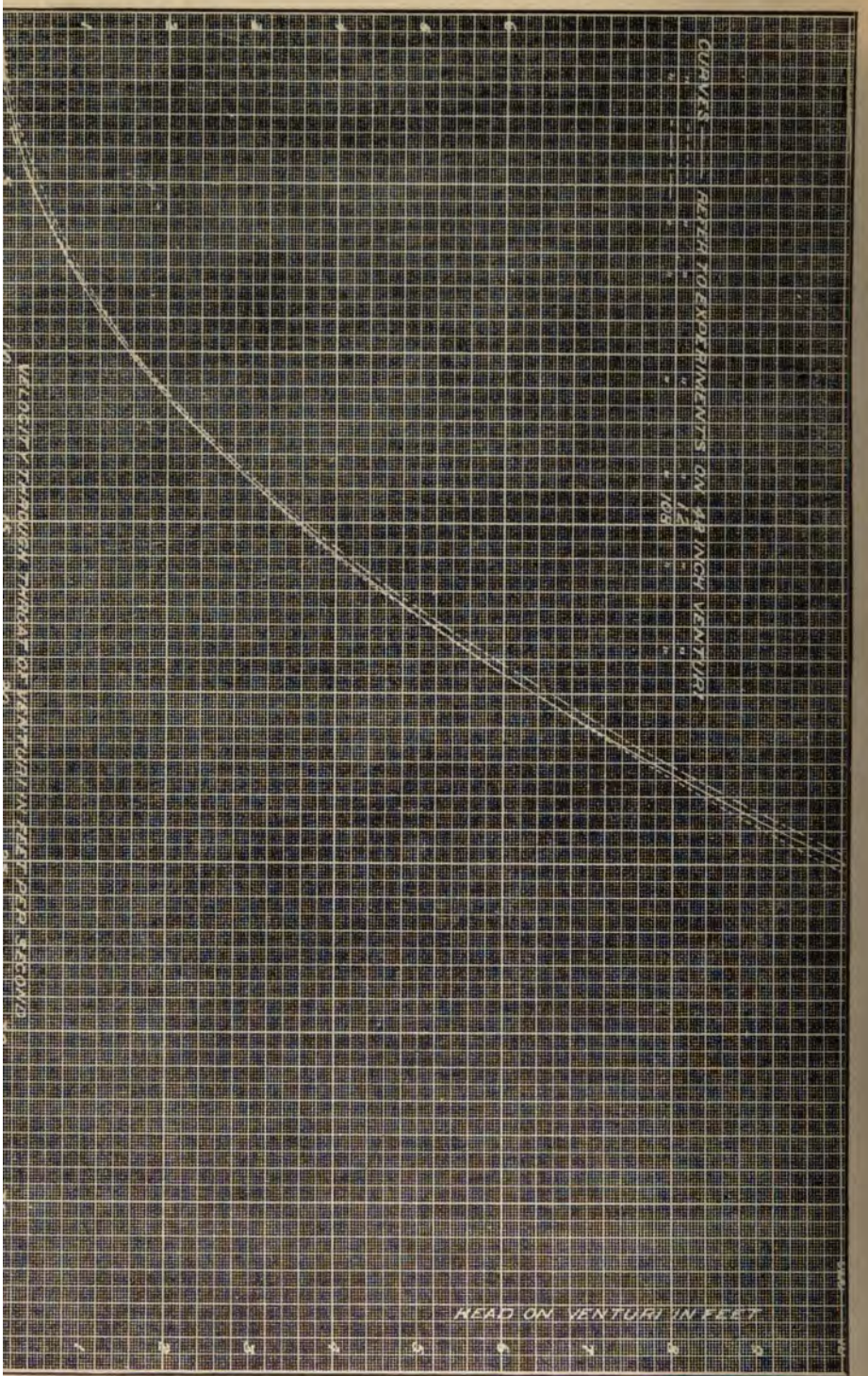


Figure 3.

Diagram of Cœfficients appertaining to the Venturi Water Meter.

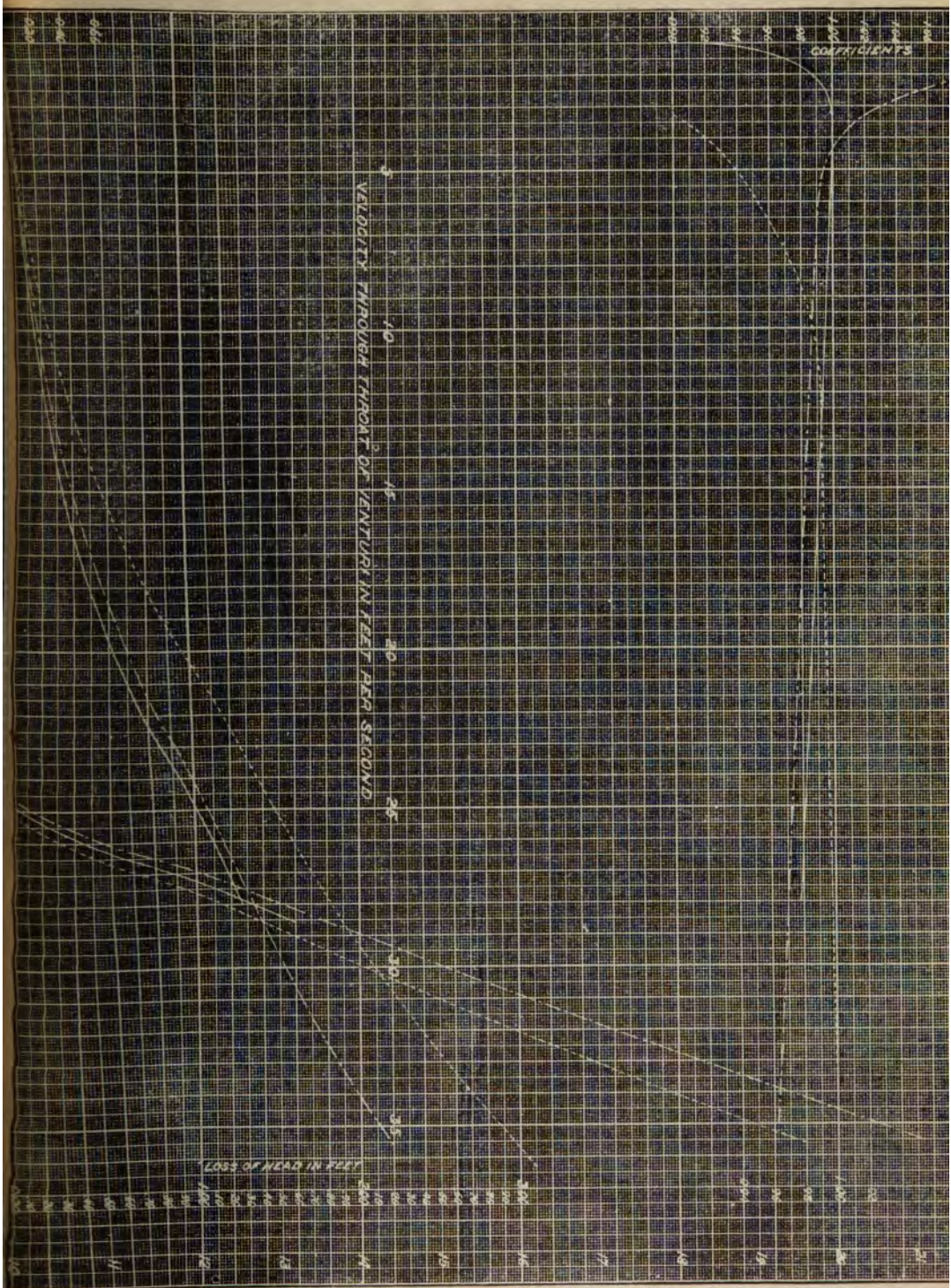


Figure 3.

Diagram of Cœfficients appertaining to the Venturi Water Meter.

Figure 2.
60-inch Venturi Water Meter, Allegheny Pumping Station, Pittsburg, Pa.

ago had thus reduced its domestic consumption to about thirty gallons per inhabitant.

The city of Newark, New Jersey, had the right to draw only 27.5 million gallons per day from the East Jersey Water Company; but in the good old-fashioned way, drew pretty much all that its inhabitants chose to use, *and* waste; until its limit of ownership was reached and then surpassed, long before the predicted time for such a draft of water. Repeated warnings fell on deaf ears, and presumably provoked smiles, rather than reforms; upon which, as all over and above 27.5 million gallons daily was under contract to be delivered elsewhere, the Venturi Meters were set to work to deal out 27.5 million gallons daily into the city reservoirs. This was done by running a liberal quantity for sixteen hours of each day; then noting the amount still due for that day, and regulating the valves so as to supply the amount lacking, during the remaining eight hours.

As a consequence, Newark became attentive to its own interests, and by reform in water works management, was still consuming less than 27.5 million gallons daily five years later; when in the ordinary course of events, she would certainly have then been consuming not less than 40 million gallons daily; and today Newark greatly cherishes the dozen or so Venturi Meters by means of which its consumption is watched, regulated, controlled and kept within proper bounds.

The East Jersey Water Company at one time supplied eleven wholesale customers. It received all the water to be distributed to its customers through two 48-inch meters, and delivered it to them through eleven others, ranging in size from 48-inch down to 16-inch. The daily records of income and outgo made by these

Figure 8.

Double-end Venturi Water Meter as laid in Oxford Street, London, England.

meters were never allowed to differ more than one per cent. If they did, the pipe-line walkers, who daily patrolled the pipe-lines, set to work to find the new leaks that had caused the increase in leakage. And apparently they always had good success in this endeavor; for these 50 miles of pipe-line, running under and over rivers, across swamps, up and down mountains, and through a rough country—some of it under 400 feet of pressure—for years was kept in condition to have its leaks well within the set limit of one per cent. of the quantity conveyed.

The eight water companies of London, or some of them, occasionally felt the need of help from an adjacent water company, in enabling the company to keep up the supply of water to its customers. As this call for aid from without was liable to come from either side of the boundry line, it gave occasion for the use of a "double-end" Venturi Meter, to measure the aid once given in one direction, and later in the reverse direction, between certain two of the companies. Such a "double-end" meter had already been used on the works of the East Jersey Water Company for a like purpose, and when facilities for an interchange of water supply became obligatory upon the London companies, this class of meters was set in numerous examples in the streets of London; by the East London Water Works, and other companies. See Figs. 7 and 8.

In the control and operation of filter plants, the Venturi Meter appears to have found a useful application. The City of Washington has more than thirty such meters at work in its Sand Filtration Plant, described in the Transactions of the American Society of Civil Engineers, 1906. Two of these, 54 and 72 inches in

diameter, are built up of reinforced concrete in place, and have only a section at the upstream end and at the throat, containing the pressure chambers, of metal.

The metal parts of two such concrete meters, to be built in place—the "record" for size, being 10-foot meters—are now being furnished for the Government of India, to be set up at Divi, Government of Madras, to check the discharge of pumps; with a maximum discharge, used for irrigation, of each meter, of about 625 cubic feet per second. These meters are to take from and discharge into an open channel, and to accomplish this, are set "submerged"; in form of an inverted siphon.*

This leads to the remark that the first two of these meters built in Holyoke, 1-foot and 9-foot diameter, and the first two built for the East Jersey Water Company, 4 feet in diameter, were built of wood; the three large ones inside of a riveted steel pipe already laid, and using the pipe as a sort of broad hoop, or envelope. They could also be built of brick; and if for metering sewage—another use to which the meter has been put—and if placed in line of a gravity sewer—not in a force main leading from a pump—the throat section could be placed with its lowest point on the *invert* line, the same as the upstream section; so as not to obstruct the passage of sand and gravel; instead of being placed concentrically with the upstream section about the *centre* line, as in the case of clear water pipes.

For testing the working efficiency, or the interior condition of force pumps, Venturi Meters have found a use in the conduct of water supply works. Such pumps have been met with having a slip, as it is called, of as much as 40 per cent.; that being the discrepancy be-

*The London "*Engineer*," May 15, 1908, contains a detailed description of this installation.

tween water actually pumped, and water indicated as pumped by computation from plunger displacement. At Buffalo a Venturi Meter is set up, that may be connected by an arrangement of valves, with any one of several pumps, and when the plunger displacement does not tally with the meter, it means that the pump valves need overhauling.

At the Washington filtration plant, the Venturi Meters established there for other purposes were used to test the efficiency of five centrifugal pumps connected with the works; when it was found that one of a pair of new pumps had 15 per cent. slip, while the other had only 3 per cent. Upon this, examination showed a misfit in the interior of the defective pump, which the engineers could then insist upon having corrected, before its acceptance.

The 10-foot Divi Madras meters above described, are another such example of Venturi Meters used to check pump delivery.

Ordinarily this means of indicating when the pump-valves need repairs, and similar detective work, are done by the meter elsewhere abroad, and in the United States; serving to reveal, and to cause to be remedied, a defective condition of the pump, which, but for it, would not be known or even suspected.

These several illustrations will serve to describe the uses that have been made, and to suggest others that may be made, of Venturi Meters in the conduct of city supply water works. For such purposes they are at work the world over. For instance: in London, Birmingham, Liverpool, Newcastle, Glasgow, Dublin, Paris, Brussells, Amsterdam, Wiesbaden, Vienna, Moscow, St. Petersburg, Warsaw, Gibraltar, Bilbao,

Figure 9.

36-inch Venturi Water Meter, as set up in 1893 at the Chicago Exposition to measure all the water delivered to the Exposition grounds.

and elsewhere in Europe; in Meerut, Lahore, Nagpur, Osaka, Hong-Kong, Penang, Singapore, Rangoon, and elsewhere in Asia; in Cairo, Capetown, Kimberley, Bloemfontein, Johannesburg, Lourenco-Marquez, and elsewhere in Africa; in Coolgardie, Sydney, Nelson (New Zealand), Brisbane, Perth, Auckland, and elsewhere in Australasia; in Boston,* New York, Philadelphia, Washington, Buffalo, Chicago, Port of Spain, St. Lucia, Vera Cruz, Buenos-Ayres, Rosario, Valparaiso, Rio de Janeiro,† Sao Paulo, and elsewhere in North and South America.

Without pretending to speak for their action elsewhere than in the United States, the author is certain that in his own country their use has already saved the expenditure of tens of millions of dollars; in postponing for long terms, the extension or enlargement of water works, by them made needless. And, of course, this good work goes on.

Incidents in the use of the meters on such works for water supply are instructive. One of the first meters exhibited was at Chicago, at the World's Columbian Exposition, in 1893. See Fig. 9. This meter served to measure all the water supplied to the Exposition, pumped from several miles away, by the Hyde Park Pumping Station, supplying some of the suburbs of Chicago. The plan adopted was to designate certain of the pumps to do this work, and then charge by the million gallons, based on pump displacement. Besides showing the invalidity of such a method

* See the Annual Reports of the Metropolitan Water and Sewerage Board, of January 1, 1903, and subsequently thereto.

† A model installation of more than 20 Venturi Meters, all registering on one panel-board, in the main office, in the city; for a description of which see *Engineering* February 22, 1907.

of gauging, which at that time was yet considered a fair one in the United States, the advent of the meter soon revealed other troubles.

The ordinary consumption of water on the Exposition grounds had long been considered to be about 11 million gallons daily; and bills on that basis were rapidly endeavoring to bankrupt the already sorely tried management, when the Venturi Meter, doing the volunteer work of a belated exhibitor, rose to remark, that the management were receiving only 7 million gallons daily.

The expressed scorn of the Pumping Station managers for that ridiculous looking meter; which pretended to pass the contents of a 36-inch force main freely through a 12-inch hole; was both loud and deep. The managers surely could not be guided by such a farce of a measurement as that; at all events, they, the pump management, would not be. Seeing was believing. So many strokes of the pump; those dimensions of the plunger pistons; so much water delivered. Great also was the distress of Mr. Connet—above named as one of the inventors of the register—when he had walked the whole length of the force main, ploughing his way through the desert of lake-shore white sand, which then bounded Chicago on the South, and could find nothing wrong about the meter, pipe-line, or pumps. But nothing daunted, he turned to walk back over the line; when a mile or more from either pump or meter, he stumbled upon a cast-iron cover, nearly buried in the sand. This, according to the pump employee present, meant nothing at all. It was "the cover of a gate-box, to shut off a branch pipe. The branch *had been* shut off before the supply commenced to the Exposition grounds, and it *was then*

shut off." "Very well," says Connet, "let us see if it is shut off"; and on application of the wrench, it was found open. Nor was there deceit in the case. The branch had been shut off, as claimed; but a pipe-walker had not been informed that it should be shut; found it shut, and had taken it upon himself to correct the supposedly unlawful procedure of some one who had shut it. Had the Venturi Meter not revealed the error, there is every reason to believe that the Exposition management would have been obliged to pay for some 1,650 million gallons, instead of for 1,050; a difference presumably of about $25,000.

In another American city, water is pumped out of the ground from clusters, or lines, of driven wells. Four pumps had been doing this work for many years without any one knowing the quantity of water thus gained. It was suspected that a large part of the pump suction out of the ground, and of the discharge, was air; which became a certainty only when a Venturi Meter was placed in the force-main, with opportunity for the air to pass off through a standpipe, before the discharge reached the meter. Upon this, experiment further showed that 3 pumps pumped as much *water* as 4 had done, and 2 pumps as much as the three.

One of the first Venturi Meters set in England was at Plymouth (whence sailed the Pilgrim Fathers in 1620).

As becomes an engineer in charge, when doing pioneer work in this way, the engineer of those works proceeded to test the meter by tank measurement; that is, by letting the discharge of the meter fill or empty a town reservoir. The letter describing this test, closed

more in sorrow than in anger, by Mr. Kent's saying that he keenly regretted that he had allowed his American friends to lead him into recommending the use of a contrivance which indicated quantities in the most erratic manner imaginable, and could not be made to register in agreement with tank measurement, whatever else it did. Of course, his American friends were as much in the dark as he was; and suggested hidden leaks, and spring inflow, and all sorts of other things; when along came an exulting second letter: "It is all right; we opened a man-hole, upstream from the meter, and found an old broom stuck in the throat." If the broom had only gone through, it may be assumed that its volume would have been correctly registered; but to stick, and continue to tickle the throat of the meter, was, of course, productive of serious error

It is curious to observe, that only six such cases are known to the author in 20 years' experience. Foreign substances get into water pipes of all sizes in far greater quantities than one would suppose, and despite the care of engineers to keep them out; but usually they pass through this make of meter without difficulty, and without being noticed. Still it may always be good engineering to have one or two man-holes near the meter, so as to get at the interior at one end or both ends when necessary. Like the revolver in Texas: "It may not be needed for a long time; but when needed was needed bad."*

* The fluid (?) occasionally supplied to meters, and thence to the consumer, is pictured in the following wail from a householder to the Water Co. of a city which shall be nameless: "Dear Sirs: I am very grateful for the gallon of water I coaxed from the tap today. The fish it contained we had for tea. I sold the microbes and bacteria to a medical society, and after we had skimmed the water off, the children made pies with the sand. Yours faithfully, ———."

WATER WASTE PREVENTION.

The case of the East Jersey Water Company's 50 miles of pipe-line has already been given as an example of water-waste prevention by a controlling and checking of leakage as it arises. On that method of work hang all the law and the prophets, relating to water-waste prevention in any kind of a hydraulic plant. In the last analysis, the prevention of water-waste depends on naught but a daily measurement of income and outgo, and the keeping of these two in constant agreement. If a meter be placed at each end of a pipe-line 23 miles long, as was done when the conduits of the East Jersey Water Company were built, it is very evident that the daily records of these two meters must agree, or else there is something wrong about either the meters, or the pipe-line; and if the meters are in order, leaks must be sought for and remedied on the pipe-line between them.

In a larger sense, the above described procedure is all that is necessary to control and check waste and leakage on any kind of a pipe-line; or system of pipe-lines; up to the case, complex but perfectly amenable to treatment, of water supplied to a city district, and consumed within it by resident families, shops and manufactories.

This opens up a large subject, but ill understood, especially in the United States, where a street-main leakage of 20 gallons per inhabitant, and more, is considered an infliction of Providence; or due to the climate; or to the peculiar habits of free-born Americans; or almost anything else except to the municipal shiftlessness not infrequently encountered in the United States, and lack of the proper amount of work expended to

control street-main leakage by the water works administration; which alone has allowed it to grow to the existing serious dimensions through the course of perhaps 50 years of frequent changes of administration.

Nor will spasmodic examinations, and reports made upon them change the situation. This is only the old story of house to house inspection of plumbing fixtures, to prevent waste on the consumers' premises, over again, and as applied to the case of cities wasting out of the street-mains. So soon as the inspector's back is turned, waste renews its insidious work, and is once more on the increase.

There is only one way to keep control of street-main leakage; and that is by a continued system of frequent, or, so long as it is necessary, of *daily* measurements; best by means of 24-hour chart records, which will serve to note the course of, or *the beginnings* of, sources of waste; and by thus first placing, and then keeping, waste under subjection.

The city should be divided into districts, any one of which should be shut off from the rest, and have its supply graphically and continuously measured and recorded at any time, day or night, and as long as desired. Then by well known means, all consumers should be metered; and once the accuracy of these meters is known, leaks and waste outside of the consumers' premises can likewise be sought for and remedied.

In an examination of this sort once made by Mr. Winslow H. Herschel, Civil Engineer, a son of the author, the final result was: that it would be profitable for the city to meter every tap, and also to check waste out of street-mains; as thereby that city could be made to supply its then inhabitants, and its future growth of

inhabitants, as well, for *fifty* years, from the quantity then consumed (used and wasted), within the city limits.

As the situation in the United States in the respects referred to may not be known to the reader, it is proper here to say that one city frequently commits the folly of pumping over 400 gallons per inhabitant per day into the sieve that represents its distribution system, the wide open plumbing fixtures of its inhabitants included; and 350 gallons per inhabitant is an ordinary quantity to be consumed in that city.

A school of water works philosophers, and bodies of complacent officials have grown up, who will argue that 150 gallons per inhabitant is too small a quantity to provide for a city, when half that quantity could readily be reached or approximated; and that city water main waste cannot be reduced to the terms that obtain in Europe; or in the distribution of gas in cities at home (frequently as low as 12 per cent. of the out-put). Yet all this time the City of Providence, Rhode Island, in the United States; a city of some 200,000 inhabitants; the centre of a large suburban district, causing many thousands of transient visitors daily in addition, and a large manufacturing centre as well; has never consumed, much, if any, over 60 gallons per inhabitant per day, and has brought this about by mere ordinary methods of good house-keeping; while smaller places in the United States have approached or reached 30 gallons per inhabitant. Let us hope that Providence and the other bright examples in the United States will not relax their vigilance and thus deprive the thrifty of their inspiration, from home sources of encouragement.

There is room for much good work to be done, so much is evident; and though hitherto the laborers have

been few, signs are not wanting and are indeed active, that a permanent work of water-waste prevention will take up much of the attention of American engineers in the future. In this work, never again to be abandoned, the Venturi Meter tube, set in line of street-mains, and its indications recorded graphically throughout the 24 hours, whether continuously as part of the year's daily routine; or at short intervals by a portable chart recorder serving many meter tubes; cannot fail to become an important factor; indeed will make the work for the first time practically and permanently possible.

Another example of water-waste prevention already in operation, is furnished by the 8 Venturi Meters set in line of the pipe-line, more than 300 miles long, of the Coolgardie Water Supply. (Minutes of Proceedings, Institution of Civil Engineers, Vol. CLXII, p. 50); which ensure that there shall be no waste or leakage between source and distribution; more than usually important in this case, where water has cost £4 per 1,000 Imperial gallons, and where 3s. 6d. per 1,000 Imperial gallons was the price after completion of the works.

WATER POWER.

The slight residuary loss of head, from upstream to downstream end of the meter (not to be confounded with the temporary loss of head experienced by the water in passing from the upstream end to the throat), all as shown in Fig. 3, will have been noticed; a smaller loss of head than is appurtenant to the weir or to any mode of measuring water, except floats or current meters and the like, which are not applicable

when it becomes a question of maintaining the pressure contained in a conduit or penstock. This small loss of head makes the Venturi Meter applicable to continuously metering the water used to generate power, in the modern cases of water power acting under the higher heads, and having water conveyed to the turbines through metal penstocks. Such a case is that of the Ogden Power Plant, owned by the Utah Light & Power Company, in the Ogden Canyon, Utah.

Two 54-inch meters, one in each of the two branch penstocks that deliver water to the Power Station, under 462 feet of head, to drive 10 or 12 impulse water wheels, meter it continuously. This Power Station is one of 4 or 5 such stations, belonging to the same Company, some driven by steam, others by water power, and all feeding into the same power lines. It is the duty of the men stationed at the Ogden Power House, to use the water available (and water in Utah is a valuable article), to the best advantage; and practically this means to properly distribute the supply among the water wheels so that they shall all work with a good efficiency; or else stand idle; storing up any excess of water thus not used; and drawing on the steam plants for power which the water plants cannot supply. For this purpose the men in charge make their daily reports in the form of a diagram, containing a graphical representation in the form of two curves; the one of the power output, and the other of the quantity of water drawn; and it is their constant aim and duty to keep these two curves parallel.

In the St. Louis Exposition of 1904, the Abner Doble Co., of San Francisco, had on exhibition one of its impulse wheels in a glass housing, and driving a

dynamo. A recording watt-meter gave the output of energy, while a chart recorder Venturi Water Meter gave the amount of water consumed; with a pressure gauge to indicate the fall; so that at any time an engineer could compute for himself, from the data at hand, what the efficiency of the combination then was, or had been.

An order for six 30-inch meters and one 12-inch meter, to operate under 230-foot head and to discharge, in all, over 500 cubic feet per second, for the Mexican Light and Power Co.; and a similar order for six 30-inch meters and one 12-inch meter, to operate under 200-foot head and to discharge, in all, over 750 cubic feet per second, for the Rio de Janeiro Tramway, Light & Power Co.; each meter to measure the water passing in a pipe penstock as it flows towards the water wheels; are to be filled within a year (Oct., 1906).

MANUFACTURING OPERATIONS.

For metering brine, acid solutions and hot water, the Venturi Meter has had a marked success. The Solvay Process Company of Syracuse, New York, U. S. A., found this to be the first meter that could be relied upon to endure the wear and tear of measuring brine under pressure; and have since, at frequent times, increased the number of these meters at work in their plants. For this purpose the register must be especially fitted, and the meter tube made wholly of bronze.

Under the pressure employed, the outside of the meter tube becomes coated with dry salt, although contrary to what one might expect, no sweating of the tube can ever be observed.

That the Venturi Meter can be used to meter all kinds

of wash-water, hot or cold, and otherwise used in manufactures, goes without further saying than has already been expressed.

IRRIGATION WATER.

The time-honored method of selling water for irrigation, is by means of a designated rate of flow, running either for the season, or for a designated day or number of days. Or else as an aliquot part of the total amount flowing in the main canal. But human nature is the same, whether influencing the draft of water for irrigation purposes, or for that of the many other uses to which man puts water; and so long as the user has no pecuniary interest in saving water—in causing the least amount of water to satisfy his needs—so long he will waste it, even if it be only for the satisfaction of letting water that has been paid for run upon the ground. Thus it has been observed that irrigation water will raise just as large crops, or even larger ones, with two acre-feet per season put on, as with six allowed to run upon the land. No man yet knows, because it has never been tried, what self-interest would teach the farmer, in increasing, what is called, the "duty" of irrigation water, were he called upon to pay for water by bulk measure; by the acre-foot, for instance, with a limit set as to the maximum amount he may at any moment draw; or by so much per season, with the same limit set, but crediting him with amounts that he may manage to save out of his season's allowance and turn back into the common water fund of the commune of which he is a member.

The same principle applied in the conduct of city water works or of power canals, has universally resulted

in a very great economy of water. When water is charged for per plumbing fixture, for instance, or per valuation of the house in which it is used, the consumer has no pecuniary interest in keeping his fixtures in order, or even merely closed when not using water; and waste grows to enormous proportions.

But when paid for by measure, use goes on as before; but waste is stopped, because attention is drawn to it with every quarterly bill rendered, and it has become costly. And thus it would be with irrigation water when paid for by measure; or when the irrigator in some manner is made to have pecuniary interest in being economical in the use of the water he may lawfully draw.

From studies made by the author, he has come to the conclusion that certainly one-half the water now used for irrigation, could be saved for the irrigation of another like quantity of land; and to state the situation in this way, will indicate the importance of the consideration involved. If it be a great gain to cause a million blades of grass to grow where none grew before; it is surely still better to cause 2 million such blades to grow, in the same locality and with no greater expenditure of water.

The cost of the whole irrigation plant and of its operation, then would become chargeable to twice the former number of water users; making each man's share of the original expense, one-half of what it has been; or to put it in another way, such a community could afford to pay for the meter that would enable this larger area of land to be irrigated as much as they paid for the original dam, canals and ditches, and yet have the satisfaction of having increased the welfare of the State, without increased cost to themselves. But meter service

would cost only a fraction of the above price, even at such a needlessly large and, at first, alarming price as $1,000 of capital to buy, set and operate a meter on each 40-acre farm. So that the result would be, to double the number of acres irrigated with the same water supply at a reduced cost for irrigation *per acre*. The next few years should see the accomplishment of many examples of this lastingly good work.

METERING COMPRESSED AIR, STEAM, ILLUMINATING GAS, AND OTHER GASES.

The Boer War interfered with an arrangement being perfected to meter air compressed at a Central Air Compressing Station, to each one of a group of mines. In a work of this sort, and in metering steam, or any *elastic* gas, allowance must of course be made for possible changes of volume, due to a permitted change of pressure.

An analysis of such cases, and the results of a number of tests of the Venturi Meter for metering steam and other gases is given in Transactions of the American Society of Mechanical Engineers for 1906; a Paper by E. P. Coleman, M. Am. Soc. M. E., Buffalo, N. Y.; with discussion.

An early example of the metering of a gas by the Venturi Meter is that of the United Water Improvement Company, of Philadelphia, Pa., purifying water by the Vosmaer Ozone process; who thus meter the ozonized air used, on its way to the bottom of the standpipe containing the water to be purified.

It is believed that the invention of the Venturi Water Meter was made sufficiently long ago, to enable the inventor to speak of it from the standpoint solely of the

hydraulic engineer, and impersonally. His old time friend and colleague, the late J. J. R. Croes, Past President, American Society of Civil Engineers, and M. Inst. C. E., has said that: "For the measurement of the flow through large pipes, such as street-mains and conduits, the invention of the Venturi Meter is sufficient to make the last quarter century noteworthy in the annals of scientific progress"; which was certainly a graceful way of referring to the meter.

But of the justness of this verdict the author must leave others to judge. His own feeling is that the meter has already been of great use and service to mankind, and in the wise economy of this earth's affairs, is destined thus indefinitely to continue; and that it will enlarge its good work.

No. 2 Wall St., New York City.
March, 1907.

NOTE A.

THE FALL-INCREASER.

A property of the Venturi tube, not utilized in the Venturi Meter, has lately been experimented on by the inventor of the Venturi Meter, and used in the construction of what has been named the fall-increaser. (See Eng'g. Record of Jan. 4th; Eng'g. News of June 11th; Harvard Eng'g. Journal of June; Zentral Blatt d. Bauverwaltung, Nov. 28th; Le Genie Civil, Nov. 21st; La Houille Blanche, Nov., for metric measures especially; all of 1908; also see Electrical World of Jan. 14th, 1909, p. 165). This apparatus will keep the power output constant during the full water half of the days of the year, where without it, such power output would range from full to half the full power output.

It will add from 10 to 15% to the annual power output, at a construction cost of only two to three times the one year's value of the Kilo-watts produced by it, by utilizing for this purpose water which otherwise would waste over the dam.

Further details may be procured of Builders Iron Foundry; or of Mr. Clemens Herschel, Hydraulic Engineer, 2 Wall Street, New York, N. Y.

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